PERIODICUM BIOLOGORUM
VOL. 118, No 3, 231–239, 2016
DOI: 10.18054/pb.2016.118.3.4074

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

original research article

Conventional and non-inversion tillage systems as a factor causing changes in ground beetle (Col. Carabidae) assemblages in oilseed rape (*Brassica napus*) fields

AGNIESZKA KOSEWSKA

Department of Entomology
Phytopatology and Molecular Diagnostic
University of Warmia and Mazury
Prawocheńskiego 17, 10-719 Olsztyn, Poland
e-mail: a.kosewska@uwm.edu.pl

Correspondence:
Agnieszka Kosewska
e-mail: a.kosewska@uwm.edu.pl

Key words: ground beetles, life traits, soil cultivation, plough

Received February 21, 2016.
Revised May 24, 2016.
Accepted July 20, 2016.

Abstract

Background and purpose: *Carabid beetles are among the most important elements of the natural environment's resistance in arable fields. In this paper, the influence of different soil tillage systems on carabid beetle assemblages in oilseed rape plantations was studied.*

Materials and methods: *The experiment was conducted in northeastern Poland. Six fields with oilseed rape cultivated under both conventional and non-inversion tillage systems were chosen. Barber traps were used to capture beetles.*

Results and conclusions: *In total 9,968 individuals belonging to 56 species were collected. Significant differences in the abundance and species richness of ground beetles in two systems of soil tillage were observed. The abundance and species richness were significantly higher in the non-inversion tillage system. Analysis of the life history traits of carabids also revealed statistically significant differences in the seasonal occurrence of carabids related to the type of soil cultivation used.*

INTRODUCTION

Disturbances caused by intensive agricultural practice, such as deep ploughing, are among the most important factors influencing the abundance and species diversity of epigeal fauna including carabid beetles *(1-5)*. The effect can be direct, i.e. by the mechanical killing of insects living in soil *(6, 7)*, or indirect, through habitat deterioration *(8, 9)*. Carabid beetles are very sensitive to various factors *(10-12)*, both caused by human activities *(13, 6, 14)* and due to the nature of habitats. In crop fields, they are dependent on all agronomic factors associated with the cultivation of plants and on the crops and microclimate in which these useful beetles live *(15-17)*.

In this study, the composition and structure of carabid beetles in oilseed rape fields are discussed. In Poland and in many other countries all over the world, oilseed rape is the most important oil plant. In global plant production, oilseeds are second to cereals. Oilseed rape occurs in human food and animal feeds, but it is also used by the chemical industry for production of biofuels, and it is an important honey plant. However, cultivation of oilseed rape requires the use of considerable amounts of pesticides because of a large number of pests (e.g. *Meligethes* *aeneus*, some species from *Ceutorrhynchus* genus, *Dasyneura brassicae*, *Brevicoryne brassicae*) *(18)*. Useful entomofauna can support farmers in their efforts to control pests. Thus, care should be taken of each element of natural plant protection, including carabid beetles.

The main aim of the study was to compare assemblages of ground beetles colonizing fields of oilseed rape cultivated under two different systems of soil tillage – conventional and non-inversion. The following research hypotheses were made: 1) ploughing causes a decrease in abundance and species richness of carabid beetles; 2) in fields under the non-inversion tillage system, which seem to be less severely disturbed owing to a more limited range of farming treatments, there are more large zoophages and fewer hemizoophages and small zoophages, more autumn breeders than spring breeders and more brachypterous and dimorphic carabid beetles. Trophic preferences are an indicator of the beetles' availability and variety. The presence of predators of variable sizes also proves the existence of a rich food base and the occurrence of some disturbance in a field, when one class of ground beetles can survive others. The lare zoophages carabids need stable habitats and may have more available prey in less disturbed soil *(19, 20)*. The presence of Carabidae in various types of development also reflects cultivation fields conditions. Autumn breeders are more desirable in cultivated fields due to the bigger number of eaten pests associated with their longer time of living. But the larval and pupae stage of autumn breeders which remain in soil for a long time are more subjected to the direct damages of soil cultivation *(2, 21)*. Additionally, the presence of beetles with differently developed wings can attest to their possible dispersion and colonization of new habitats so as to avoid hazards in the form of agricultural treatments *(6)*.

MATERIAL AND METHODS

The experiment was conducted in northeastern Poland, near Olsztyn. Six fields with oilseed rape under two different systems of soil tillage were chosen. Three of the fields were subjected to conventional soil tillage, with furrow slice turning ploughs followed by a tiller and harrows used to prepare soil for sowing. The other three fields underwent reduced tillage further referred to as non-inversion tillage, where soil was cultivated with special soil mixing aggregates without the turning of furrows or slicing. The soils under plantations were similar and belonged to class IIIa and IIIb according to the Polish arable soil classification system. The oilseed rape fields were surrounded by other crop fields, stretching over the perimeter of about 20 km. The distance between the fields was at least 300 meters. In conventional tillage, ploughing was performed in August, in the year preceding the collection of carabid beetles. Oilseed rape was sown at the end of August in both tillage systems. Modified Barber traps were used to capture insects. In each of the six study sites, six Barber traps were put deep in the fields, at about 20-meter distance from each other. The first trap on each field was placed about 50 meters from the field's edge. The traps were emptied every two weeks. Carabid beetles were caught from April to October 2011, when their activity is high. The seasonal variation was included in the analysis as a season. The traps were removed during harvest and while the soil was tilled for sowing.

The carabid beetles were analysed in terms of their species composition, abundance, richness (as a total number of species) and some life history traits – trophic preferences, type of breeding and dispersal mobility *(22)*. Trophic groups were specified on the basis of various studies *(23, 24, 25, 26)*: hemizoophagous (eating both – animals and plant food) and zoophagous divided into groups according to their body size: small zoophagous (body length less than 5 mm), medium zoophagous (5.1 -15 mm) and large zoophagous (body length more than 15 mm). They were classified according to development as: autumn breeders that reproduce in autumn and hibernate as larvae, and spring breeders that hibernate as adults and reproduce in spring *(27)*. They were also divided into three groups depending on their mobility: macropterous (fully developed wings), brachypterous (with wings reduced to a various extent) and dimorphic *(24, 25)*. The Carabidae's life history elements which were taken into consideration describe the best groups of carabids in cultivated fields.

Differences in means of parameters describing assemblages (species abundance and richness and life history traits abundance) were tested using a Poisson generalized linear model (GLM), which included two factors (the soil cultivation system and the sampling period). Indirect ordination of carabid beetle assemblages found at the study area was performed using non-metric multidimensional scaling (NMDS). NMDS was calculated in WinKyst 1.0 *(28)* on a Bray-Curtis similarity matrix. Data were non-transformed. The significance of multivariance differences among Carabidae assemblages was tested with a non-parametric analyses of variance PERMANOVA (NPMANOVA) tests with 9,999 permutations *(29)*.

RESULTS

In total 9,968 individuals belonging to 56 species were collected (Table 1). The most numerous species living in oilseed rape fields were *Poecilus cupreus*, *Harpalus rufipes*, *Anchomenus dorsalis* and *Pterostichus melanarius*. *P. cupreus* reached more than half of assemblages in both systems, and the remaining dominants were the same in the two studied systems of tillage.

Comparing the total number of individuals and the overall richness, we can see that there were more individuals and species in the fields under reduced tillage than in the conventional fields (Table 1). The Shannon diversity index reached a higher value in conventional fields but this

Table 1. *Species composition, abundance and diversity of Carabidae caught in the two types of studied fields*

Species	Type of cultivation					
	Non-inversion (fields)			Conventional (fields)		
	1	2	3	1	2	3
Amara aenea (Degeer,1774)	4	4	0	3	4	2
Amara bifrons (Gyllenhal,1810)	0	1	0	2	0	0
Amara communis (Panzer,1797)	1	4	0	1	0	1
Amara convexior Stephens,1828	13	8	7	5	5	0
Amara lunicollis Schiodte,1837	1	0	0	0	0	0
Amara ovata (Fabricius,1792)	62	29	28	41	22	27
Amara plebeja (Gyllenhal,1810)	2	1	2	0	2	3
Amara similata (Gyllenhal,1810)	50	35	23	34	26	23
Anchomenus dorsalis (Pontoppidan,1763)	153	117	95	60	62	60
Anisodactylus binotatus (Fabricius,1787)	12	5	14	17	8	4
Asaphidion flavipes (Linnaeus,1761)	0	0	0	2	1	1
Bembidion guttula (Fabricius,1792)	1	2	1	0	2	1
Bembidion lampros (Herbst,1784)	7	6	5	2	3	5
Bembidion properans (Stephens,1828)	6	4	5	2	6	1
Bembidion quadrimaculatum (Linnaeus,1761)	0	2	0	2	1	4
Bembidion tetracolum Say,1823	1	0	0	0	0	0
Blemus discus (Fabricius,1792)	1	0	0	0	0	0
Blethisa multipunctata (Linné, 1758)	0	0	0	0	1	0
Broscus cephalotes (Linnaeus,1758)	0	0	0	1	1	0
Calathus ambiguus (Paykull,1790)	1	0	0	1	0	0
Calathus cinctus Motschulsky,1850	1	0	0	1	0	1
Calathus erratus (Sahlberg,1827)	0	0	0	1	0	0
Calathus fuscipes (Goeze,1777)	10	13	10	4	14	5
Calathus halensis (Schaller,1783)	0	6	3	0	0	0
Calathus melanocephalus (Linnaeus,1758)	0	1	0	0	0	0
Carabus cancellatus Illiger, 1798	1	0	0	0	0	0
Carabus granulatus Linnaeus,1758	55	28	31	7	7	4
Carabus nemoralis O.F.Muller,1764	1	2	0	0	1	0
Clivina fossor (Linnaeus,1758)	1	4	2	1	1	1
Curtonotus aulicus (Panzer,1797)	0	2	0	0	1	0
Harpalus affinis (Schrank,1781)	1	8	3	3	4	3
Harpalus griseus (Duftschmid,1812)	1	1	1	2	0	0
Harpalus latus (Linnaeus,1758)	0	0	0	1	0	0
Harpalus luteicornis (Duftschmid,1812)	2	3	3	0	3	0
Harpalus progrediens Schauberger,1922	0	1	0	0	0	0
Harpalus laevipes Zetterstedt, 1828	1	0	1	0	0	0
Harpalus rubripes (Duftschmid,1812)	1	0	1	0	1	1
Harpalus rufipes (Degeer,1774)	278	234	201	111	119	91
Harpalus signaticornis (Duftschmid,1812)	3	7	6	1	3	2
Harpalus tardus (Panzer,1797)	6	4	2	5	1	1
Limodromus assimilis (Paykull,1790)	5	9	3	0	4	8
Leistus terminatus (Panzer,1793)	0	0	0	1	0	0
Loricera pilicornis (Fabricius,1775)	6	7	7	5	1	1
Nebria brevicollis (Fabricius,1792)	1	5	2	1	0	0
Notiophilus biguttatus (Fabricius,1779)	0	1	0	0	0	0
Notiophilus palustris (Duftschmid,1812)	0	1	1	0	0	0
Ophonus rufibarbis (Fabricius,1792)	3	0	1	0	0	0

Poecilus cupreus (Linnaeus,1758)	1452	1485	1662	617	814	716
Poecilus lepidus (Leske,1785)	3	2	3	0	3	4
Poecilus versicolor (Sturm,1824)	20	17	15	7	12	8
Pterostichus melanarius (Illiger,1798)	101	108	103	54	40	39
Pterostichus niger (Schaller,1783)	14	36	29	3	0	2
Pterostichus nigrita (Paykull,1790)	0	0	0	0	1	0
Pterostichus oblongopunctatus (Fabricius,1787)	0	2	0	0	0	0
Pterostichus vernalis (Panzer,1796)	0	1	1	1	0	0
Trechus quadristriatus (Schrank,1781)	4	5	3	0	3	2
Total Individuals	2286	2211	2274	999	1177	1021
		6771			3197	
Total Species	39	40	33	33	33	29
		49			44	
Shannon H' Log Base 2,718	1.48	1.43	1.20	1.56	1.35	1.30
		1.38			1.42	
Shannon J'	0.40	0.39	0.34	0.45	0.39	0.39
		0.36			0.38	

Table 2. *GLM effect of type of soil tillage and period when sampled on abundance and species richness of Carabidae assemblages*

Abundance	df	Wald Stat.	p
Date	9	3262.41	0.00
Treatment	1	224.11	0.00
Date*Treatment	9	800.82	0.00
Richness	df	Wald Stat.	p
Date	9	203.34	0.00
Treatment	1	37.63	0.00
Date*Treatment	9	6.68	0.67

result was closely connected with the relatively big number of species relative to the number of individuals (Table 1). The abundance and richness of ground beetles significantly depended on arable field treatment and season (Table 2). There were significant differences in seasonal abundance recorded in the two tillage systems (Figure 1). The peak-abundance in the non-inverted sites was observed between May and June, whereas in the conventional fields it occurred later and was almost nonexistent. The abundance in the fields under conventional treatment was significantly lower than in the non-inverted ones. There was also a significant increase in species richness in non-inverted sites (Figure 2). The combination of treatment and season had no significant effect on the richness of ground beetles (Table 2). The non-metric multidimensional scaling analysis (NMDS) grouped separately assemblages of ground beetles in fields under conventional and non-inversion tillage (Figure 3). The final two-dimensional solution of the NMDS ordination represented a total of 93% of the total variation of the original space at a final stress of 0.06 (Monte Carlo test, P=0.0001). The PERMANOVA test revealed significant differences in the species composition of the ground beetle assemblages in the two types of oilseed rape cultivation (F=10.54; p<0.001).

Analysis of the chosen life history traits of food preference and body size of the carabids revealed statistically significant differences in term of the seasonal presence of the mentioned groups of carabids correlated with the type of soil cultivation (Table 3). The highest differences between assemblages were manifested by the highest abundance of medium-size zoophages (Figure 4). In the non-inversion tillage system, peak abundance of medium-sized zoophages was between May and June; the abundance of this group of beetles in the conventional fields was significantly lower. Hemizoophages were less abundant in the conventionally cultivated fields than in the reduced

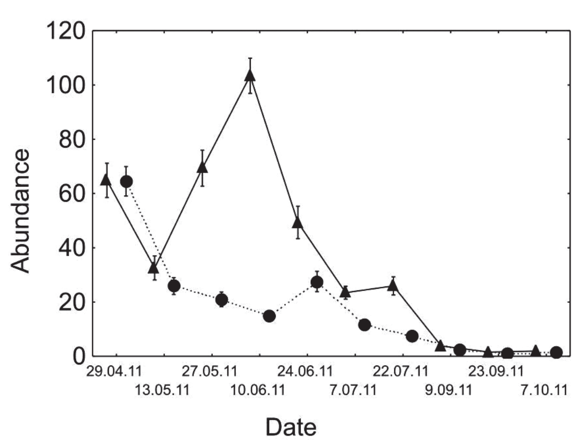

Figure 1. *Average abundance of the carabids recorded during the course of a year in oilseed rape fields in which the soil was cultivated in one of two different ways: N – non-inversion, C – conventional (The vertical lines show standard errors)*

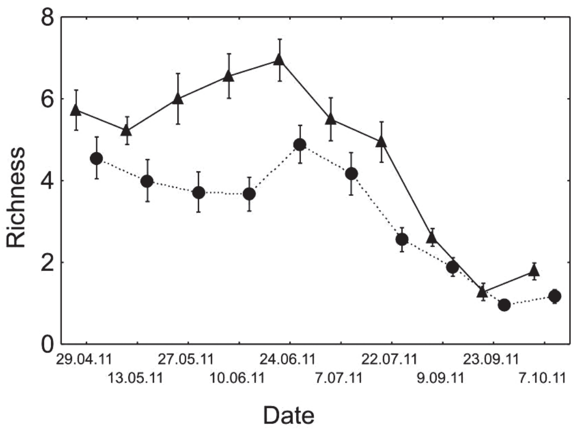

Figure 2. *Average species richness of the carabids recorded during the course of a year in oilseed rape fields in which the soil was cultivated in one of two different ways: N – non-inversion, C – conventional (The vertical lines show standard errors)*

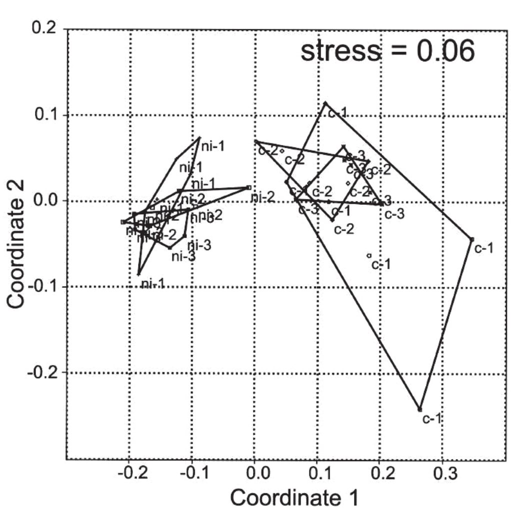

Figure 3. *Diagram of non-metric multidimensional scaling (NMDS) performed on Bray-Curtis similarity matrix of ground beetle assemblages, ni- assemblages of non-inversion tillage, c- assemblages of conventional tillage*

soil cultivated fields, especially in the middle of July. After summer, the abundance of hemizoophages declined drastically (Figure 4). There were no significant differences between the sites with two soil tillage methods in terms of the number of small and large zoophages, however the effect was also dependent on seasonal dynamic (Table 3).

Having analyzed carabid beetles with different dispersion possibilities in the two types of soil cultivation we noted that macropterous Carabidae dominated in both treatments (Table 3). In the non-inversion tillage, they occurred in significantly higher number than in the conventional one. The peak activity was observed at the beginning of June, while a small increase in the activity of beetles was recorded two weeks later under conventional cultivation (Figure 5). Although the abundance of brachypterous carabids differed significantly between the sites in relation to the method of cultivating the soil, their number in the samples was too small to draw conclusions as to the preferred method of cultivating the soil for this group of beetles. The sites with applied tillage had no significant differences in abundance of dimorphic species,

Table 3. *Results of the GLM test of significance (Wald statistics) of the effect of type of soil tillage and period when sampled on some life traits of carabid beetle assemblages*

	df	Wald Stat.	p
Medium zoophages			
Date	9	3062.05	0.00
Treatment	1	54.90	0.00
Date*Treatment	9	752.98	0.00
Hemizoophages			
Date	9	718.55	0.00
Treatment	1	20.44	0.00
Date*Treatment	9	98.35	0.00
Large zoophages			
Date	9	218.34	0.00
Treatment	1	0.00	0.99
Date*Treatment	9	62.44	0.00
Small zoophages			
Date	9	26.07	0.00
Treatment	1	0.00	1.00
Date*Treatment	9	17.57	0.04
Macropterous			
Treatment	1	139.56	0.00
Date	9	3172.83	0.00
Treatment*Date	9	771.21	0.00
Brachypterous			
Treatment	1	32.25	0.00
Date	9	113.39	0.00
Dimorphic			
Treatment	1	0.00	1.00
Date	9	207.54	0.00
Treatment*Date	9	50.18	0.00
Spring breeders			
Date	9	3636.46	0.00
Treatment	1	83.63	0.00
Date*Treatment	9	745.77	0.00
Autumn breeders			
Date	9	743.81	0.00
Treatment	1	0.00	1.00
Date*Treatment	9	89.79	0.00

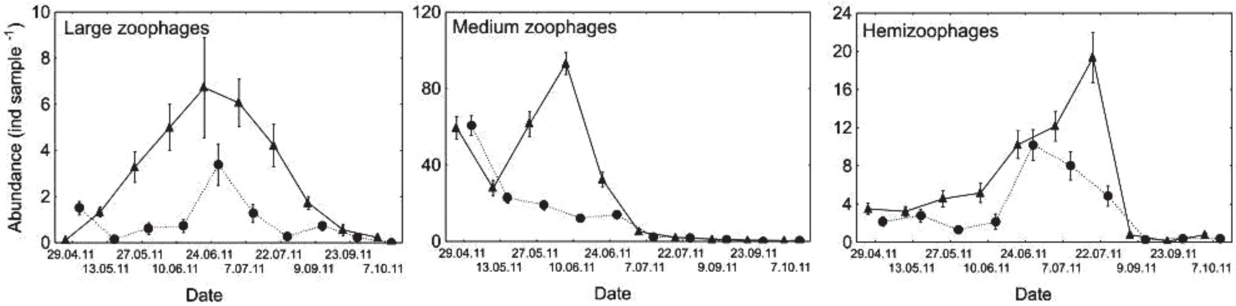

Figure 4. *Average abundance of carabids belonging to different trophic groups recorded during the course of a year in oilseed rape fields in which the soil was cultivated in one of two different ways: N – non-inversion ▲, C – conventional ●. (The vertical lines show standard errors)*

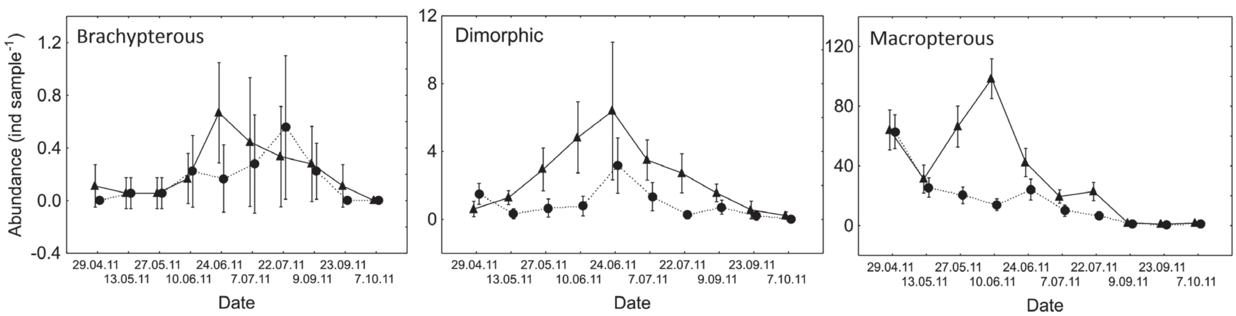

Figure 5. *Average abundance of carabids belonging to different dispersal groups recorded during the course of a year in oilseed rape fields in which the soil was cultivated in one of two different ways: N – non-inversion ▲, C – conventional ●. (The vertical lines show standard errors)*

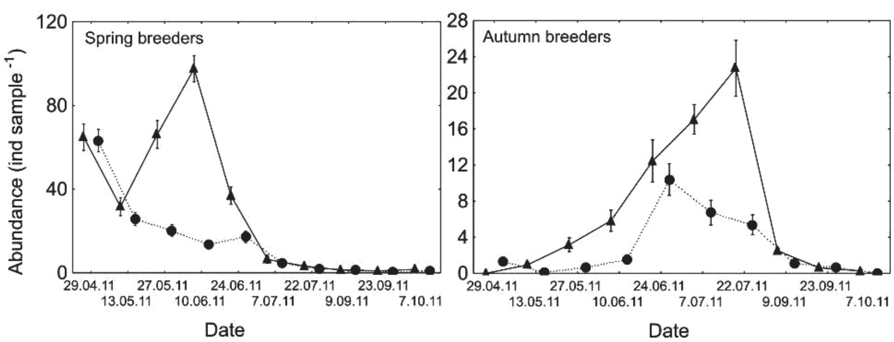

Figure 6. *Average abundance of spring and autumn breeding carabids recorded during the course of a year in oilseed rape fields in which the soil was cultivated in one of two different ways: N – non-inversion ▲, C – conventional ●. (The vertical lines show standard errors)*

but considering both parameters – tillage and occurrence in season – it was statistically significant.

The analyzed occurrence of spring and autumn breeding carabids showed that autumn breeders were represented by smaller number of specimens than spring breeders (Table 3). However, the significant decrease of autumn breeders in the conventional treatment occurred in the season. The abundance of spring breeders was also lower in sites with the conventional treatment. In the non-inversion system, strong seasonal division between spring and autumn breeders was visible (Figure 6).

DISCUSSION

Soil is an essential element of agriculture, both for crops and field-dwelling entomofauna. Changes in soil associated with farming can contribute to changes in the species composition of entomofauna living in the soil permanently or during a stage in its development *(30, 19, 7, 31)*. Disturbances caused by agricultural practice are among the most important factors influencing soil fauna such as ground beetles *(1-3, 5)*. Conventional soil tillage using slice furrow inversion with a plough destroys the structure of soil, thereby changing the environmental occurrence of its fauna *(32, 6, 1, 33)*. Deep interference into the structure of soil is a factor that disturbs the development of soil-dwelling organisms directly, causing their death or mechanical damage, and indirectly, by modifying properties of the habitat and food availability. Simplified soil technologies, such as non-inversion tillage, can mitigate negative consequences of soil cultivation to soil fauna. However, they are not recommended for growing oilseed rape because they provide fewer opportunities of reducing the abundance of pest insects responsible for yield decline *(18)*. The study confirms that the number of beetles was significantly higher in the fields with non-inversion tillage than under conventional cultivation. However, the literature data suggest that the effect of tillage on soil beetles is not clear. Many authors point to the negative impact of conventional tillage on assemblages of beetles, mainly due to the devastating effects of ploughing on soil-dwelling larva, with the resulting reduction in the number and activity of adult insects *(13, 34-37, 32, 6, 30, 3, 4)*. The reduced activity of carabid beetles in simplified cultivation is also reported *(38, 39, 21, 7)*. Some authors prove that the method of soil cultivation is not important to the formation of Carabidae assemblages *(40-43)*. The study on Carabidae in oilseed rape supports the opinion that deep ploughing had a significant negative effect on the number of beetles. In the case of species richness differences were evident between the sites and especially combining sites and the seasons. Also, the comparison of dominant species in both types of crops showed that they were the same (Table 1). But the diversity, higher in conventional cultivation, was created by other, less numerous species. This is also visible in the NMDS diagram, which shows different significant assemblages of Carabidae depending on the method of soil cultivation, with greater variation in the case of conventional tillage (larger distances in the first two dimensions). Thus, in terms of protecting plants against pests, the sites with non- inversion tillage system seem to be more favorable because of the higher number of common prey species such as *Poecilus cupreus* and *Pterostichus melanarius* (Table 1). However, higher species diversity, owing to rare species, was observed in the conventional system, which is important for nature conservation. Different results were obtained by Hatten et al. *(7),* who showed a higher diversity of species in the crop without ploughing. Holland & Luff *(1)* also claimed that tillage simplifications enhanced the diversity of epigeic arthropods as carabids, which has been confirmed in the current research. The analyzed results of the research show the importance of further study to examine the elaborate dependences of species diversity.

Agricultural practice can influence the abundance, species richness as well as life traits of carabid beetles via soil intervention. Trait specific responses to farming practice become increasingly apparent for a variety of traits and taxa *(44)*. This applies mainly to trophic preferences. Purtauf et al. *(45)* and Schweiger et al. *(46)* showed the responses of carabids to management and landscape structure in different trophic groups. It was shown that hemizoophagous were less vulnerable to simplifications then carnivorous species. In this study, the activity of hemizoophagous carabids had a similar pattern in both types of soil cultivation, but their number was higher in the non-inversion sites. The strongest reaction to the cultivation method was shown by medium zoophages. Evidently, their higher number was observed in crops that were grown in unploughed soil. The most desirable group of ground beetles in crops are large zoophages, perceived as a component of the natural, environmental resistance against pests. However, in our study, this group was not numerous and showed no differences between the sites with different method of cultivation. Large zoophages are not common in agrocenoses because of some unfavorable conditions regarding moisture, microhabitats, agrotechnical treatments, etc. Szyszko *(47)*, Blake at al. *(48)* and Skalski et al. *(49)* showed that the high level of environmental disturbances caused by human activity affects assemblages of beetles regarding the body size in favour of smaller size insects. This is partly verified by studies in which a low number of large predators and a higher number of medium size zoophages were observed in habitats like fields strongly disturbed by human activity. However, the latter decrease in number when additional disorders such ploughing take place. Ribera et al. *(2)* and Eyre et al. *(5)* claimed that the intensity of agricultural management influenced ground beetles, and small species with their high dispersal capability could tolerate more intensively managed areas while larger species were less inclined to flee over larger distances to less affected habitats. In this study, small zoophages constituted a very small group and did not differ between the sites under the different methods of cultivation. However, taking into consideration the dispersion abilities of macropterous carabid beetles, they were far more numerous and less vulnerable to human interference in crops without ploughing. This contradicts the opinion of Shibuya et al *(50)* that macropterous carabid beetles are more common in disturbed habitats comparing forest and open areas without any land management practice. Brachypterous carabid beetles were very few and, like dimorphic Carabidae, did not show differences in the two methods of cultivation along the seasonal dimension. In respect of the energy budget, autumn-breeders are a more desirable group of Carabidae in fields. They remain in fields much longer than the spring-breeders, so they can contribute to the prevention of pest gradation over a longer period of time. Autumn breeders overwinter as larvae and, as Lovei & Sunderland *(10)* showed, they are more sensitive to disturbance because of the lower mobility of larvae. In this study, this claim has not been clearly confirmed, as autumn-breeders present in the tested oilseed rape showed no significant differences between the sites grouped according to the method of soil cultivation. It was only after including the second factor, i.e. their presence in season that they gained statistical significance and were significantly more numerous in the sites with non-inversion tillage. However, spring beetles, which have much less time for feeding and reproduction due to the type of development, responded strongly to the method of cultivation, evidently preferring fields without ploughing. As demonstrated by this research, a negative effect on carabid beetles assemblages were noted on the sites with conventional management applied, although, as Holland & Luff *(1)* emphasize, there can be various causes of differences between ground beetles assemblages, such as prevalent local conditions.

CONCLUSIONS

The type of soil tillage may have an appreciable effect on assemblages of ground beetles. Modifications of the soil environment, for example by ploughing, can lead to a decrease in the abundance and richness of carabid beetles.

The use of simplifications like non-inversion tillage enhanced the activity of macropterous, medium-sized zoophages with the spring type of development. The effect of sites grouped according to tillage management was season dependent, also among the less frequently occurring groups of large zoophages and autumn breeding carabids.

REFERENCES

1. HOLLAND J M, LUFF M L 2000 The effects of agricultural practices on Carabidae in temperate agroecosystems. Integr Pest Manag Rev 5: 109–129 http://dx.doi.org/10.1023/A:1009619309424
2. RIBERA I, DOLEDEC S, DOWNIE I S, FOSTER G N 2001 Effect of land disturbance and stress on species traits of ground beetle assemblages. Ecology 82: 1112–1129 http://dx.doi.org/10.1890/0012-9658(2001)082[1112:EOLDAS]2.0.CO;2
3. TWARDOWSKI J 2010. The effect of reduced tillage systems in winter wheat crop on the assemblages of epigeal and soil arthropods. Monographs, Wrocław University of Environmental and Life Sciences, p 141
4. KOSEWSKA A, SKALSKI T, NIETUPSKI M 2014 Effect of conventional and non-inversion tillage systems on the abundance and some life history traits of carabid beetles (Coleoptera: Carabidae) in winter triticale fields. Eur J Entomol 111(5): 669–676 http://dx.doi.org/10.14411/eje.2014.078
5. EYRE M D, SANDERSON R A, MCMILLAN S D, CRITCHLEY C N R 2016 Crop cover the principal influence on non-crop ground beetle (Coleoptera, Carabidae) activity and assemblages at the farm scale in a long-term assessment. B Entomol Res, http://dx.doi.org/10.1017/S0007485315001054
6. KROMP B 1999 Carabid beetles in sustainable agriculture: a review of pest control efficacy, cultivation impact and enhancement. Agr Ecosyst Environ 74: 187–228 http://dx.doi.org/10.1016/S0167-8809(99)00037-7
7. HATTEN T D, BOSQUE-PÉREZ N A, LABONTE J R, GUY S O, EIGENBRODE S D 2007 Effects of tillage on the activity density and biological diversity of carabid beetles in spring and winter crops. Environ Entomol 36 (2): 356–368 http://dx.doi.org/10.1093/ee/36.2.356
8. HANCE T 2002 Impact of cultivation and crop husbandry practices. In: Holland J.M. (ed). The Agroecology of Carabid Beetles. Intercept, Andover, UK: p 231–250
9. TWARDOWSKI J P 2006 The effects of non-inversion tillage systems in winter oilseed rape on ground beetles (Coleoptera: Carabidae). Integrated Control in Oilseed Crops IOBC wprs Bulletin, Electronic version only (CD). ISBN 1901396096
10. LÖVEI G L, SUNDERLAND K D 1996 Ecology and behavior of ground beetles (Coleoptera: Carabidae). Annu Rev Entomol 41: 231–256 http://dx.doi.org/10.1146/annurev.en.41.010196.001311
11. KOTZE J D, BRANDMAYR P, CASALE A, DAUFFY-RICHARD E, DEKONINCK W, KOIVULA M J, LÖVEI G L, MOSSAKOWSKI D, NOORDIJK J, PAARMANN W, PIZZOLOTTO R, SASKA P, SCHWERK A, SERRANO J, SZYSZKO J, TABOADA A, TURIN H, VENN S, VERMEULEN R, ZETTO T 2011 Forty years of carabid beetle research in Europe – from taxonomy, biology, ecology and population studies to bioindication, habitat assessment and conservation. ZooKeys 100: 55–148
12. KOIVULA M J 2011: Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. – ZooKeys 100: 287–317 http://dx.doi.org/10.3897/zookeys.100.1533
13. THIELE H U 1977 Carabid Beetles in their Environments. A Study on Habitat Selection by Adaptation in Physiology and Behavior. Zoophysiology and Ecology 10. Springer Verlag, Berlin, p 369
14. SKŁODOWSKI J J 2014 Effects of top-soil preparation and broadleaved tree mixture on carabid beetles in afforested fallow plots. Restor Ecol 22: 13–21 http://dx.doi.org/10.1111/rec.12034
15. DUELLI P, OBRIST M K, SCHMATZ D R 1999 Biodiversity evaluation in agricultural landscapes: above-ground insects. Agric Ecosyst Environ 74: 33–64 http://dx.doi.org/10.1016/S0167-8809(99)00029-8
16. SUNDERLAND K D 2002 Invertebrate pest control by carabids. In: Holland J M (ed.): The agroecology of Carabid Beetles. Intercept, Andover, p 165–214
17. EYRE M D, SANDERSON R A, SHOTTON P N, LEIFERT C 2009 Investigating the effects of crop type, fertility management and crop protection on the activity of beneficial invertebrates in an extensive farm management comparison trial. Ann Appl Biol 155: 267–276
18. SĄDEJ W, CIEPIELEWSKA D, NIETUPSKI M 1996 Ochrona rzepaku przed szkodnikami. Oilseed Crops. 19(2): 353–360
19. KLADIVKO E J 2001 Tillage systems and soil ecology. Soil Till Res 61: 61–76 http://dx.doi.org/10.1016/S0167-1987(01)00179-9
20. EYRE M D, LUFF M L, LEIFERT C 2013 Crop, field boundary, productivity and disturbance influences on ground beetles (Coleoptera, Carabidae) in the agroecosystem. Agr Ecosyst Environ 165: 60–67
21. CÁRCAMO H A, NIEMELÄ J, SPENCE J R 1995 Farming and ground beetles: effects of agronomic practice on populations and community structure. Can Entomol 127: 123–140
22. TURIN H 2000 De Nederlandse loopkevers, verspreiding en oecologie (Coleoptera: Carabidae). Nederlandse Fauna 3. National Natuurhistorisch Museum Naturalis KNNV Uitgeverij EIS-Nederland Leiden, p 666
23. KOCH K 1989 Die Käfer Mitteleuropas. Ökologie Goecke & Evers Verlag Krefeld, p 413
24. HŮRKA K 1996 Carabidae of the Czech and Slovak Republics.- Kabournek – Zlin, p 565
25. DESENDER K, DEKONINCK W, MAES D m m v CREVECOEUR L, DUFRÊNE M, JACOBS M, LAMBRECHTS J, POLLET M, STASSEN E, THYS N 2008 Een nieuwe verspreidingsatlas van de loopkevers en zandloopkevers (Carabidae) in

België. Rapporten van het Instituut voor Natuur-en Bosonderzoek 2008 (INBO.R.2008.13). Instituut voor Natuur-en Bosonderzoek Brussel, p 184

26. ALEKSANDROWICZ O 2014 Ground beetles (Coleoptera Carabidae) west of the forest zone of the Russian Plain. Fauna zoogeography ecology faunogenesis. Lambert Academic Publishing, Saarbrücken, p 461

27. LARSSON S G 1939 Entwicklungstypen und Entwicklungszeiten der dän Carabiden. Entom Meddelels 20: 270–560

28. ŠMILAUER P 2002 WinKyst 1.0, Ceske Budejovice, Czech Republic

29. ANDERSON M 2001 A new method for non-parametric multivariate analysis of variance. Austral Ecol 26: 32–46

30. ANDERSEN A 1999 Plant protection in spring cereal production with reduced tillage. II. Pests and beneficial insects. Crop Prot 18: 651–657 http://dx.doi.org/10.1016/S0261-2194(99)00071-X

31. TWARDOWSKI J, SMOLIS A, KORDAS L 2004 Wpływ różnych systemów uprawy roli na mezofaunę glebową. Annales Universitatis Marie Curie-Skłodowska Lublin Polonia 59(2): 817–824

32. STINNER B R, HOUSE G J 1990 Arthropods and other invertebrates in conservation-tillage agriculture. Annu Rev Entomol 35: 299–318 http://dx.doi.org/10.1146/annurev.en.35.010190.001503

33. HOLLAND M J 2004 The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agr Ecosyst Environ 103: 1–25 http://dx.doi.org/10.1016/j.agee.2003.12.018

34. HOUSE G J, PARMELEE R W 1985 Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Till Res 5: 360

35. LUFF M L 1987 Biology of polyphagous ground beetles in agriculture. Agric Zool Rev 2: 237–278

36. PURVIS G, FADL A 1996 Emergence of Carabidae (Coleoptera) from pupation: A technique for studying the 'productivity' of carabid habitats. Ann Zool Fenn 33: 215–223

37. HOLLAND J M, REYNOLDS C J M 2003 The impact of soil cultivation on arthropod (Coleoptera and Aranae) emergence on arable land. Pedobiologia 47: 181–191 http://dx.doi.org/10.1078/0031-4056-00181

38. BARNEY R J, PASS B C 1986 Ground beetle (Coleoptera: Carabidae) populations in Kentucky alfalfa and influence of tillage. J Econ Entomol 79: 511–517 http://dx.doi.org/10.1093/jee/79.2.511

39. BAGUETTE M, HANCE T 1997 Carabid beetles and agricultural practices: influence of soil ploughing. Biol Agric Hortic 15: 185–190 http://dx.doi.org/10.1080/01448765.1997.9755193

40. TYLER B M J, ELLIS C R 1979 Ground beetle in three tillage plots in Ontario and observations on their importance as predators of the northern corn rootworm, *Diabrotica longicornis* (Coleoptera: Chrysomelidae). Proc Ent Soc Ontario 110: 65–73

41. HUUSELA-VESITOLA E 1996 Effects of pesticide use and cultivation techniques on ground beetles (Col., Carabidae) in cereal fields. Ann Zool Fenn 33: 197–205

42. ANDERSEN A 2003 Long-term experiments with reduced tillage in spring cereals. II. Effects on pest and beneficial insects. Crop Prot 2: 147–152 http://dx.doi.org/10.1016/S0261-2194(02)00133-3

43. GAILIS J, TURKA I 2014 The diversity and structure of ground beetles (Coleoptera: Carabidae) assemblages in differently managed winter wheat fields. Baltic J Coleopterol 14 (1): 33–46

44. WAMSER S, DIEKÖTTER T, BOLDT L, WOLTERS V, DAUBER J 2012 Trait-specific effects of habitat isolation on carabid species richness and community composition in managed grasslands. Insect Conserv Divers 5: 9–18 http://dx.doi.org/10.1111/j.1752-4598.2010.00110.x

45. PURTAUF T, DAUBER J, WOLTERS V 2005 The response of carabids to landscape simplification differs between trophic groups. Oecologia 142(3): 458–464 http://dx.doi.org/10.1007/s00442-004-1740-y

46. SCHWEIGER O, MAELFAIT J P, VAN WINGERDEN W, HENDRICK F, BILLETER R, SPEELMANS M, AUGENSTEIN I, AUKEMA B, AVIRON S, BAILEY D, BUKACEK R, BUREL F, DIEKOTTER T, DIRKSE J, FRENZEL M, HERZOG F, LIIRA J, ROUBALOVA M, BUGTER R 2005 Quantifying the impact of environmental factors on arthropod communities in agricultural landscapes across organizational levels and spatial scales. J Appl Ecol 42: 1129–1139

47. SZYSZKO J 1983 State of Carabidae (Col.) fauna in fresh pine forest and tentative valorization of this environment. Agricultural University Press, Warsaw

48. BLAKE S, FOSTER G N, EYRE M D, LUFF M L 1994 Effects of habitat type and grassland management practices on the body size distribution of carabid beetles. Pedobiologia 38: 502–512

49. SKALSKI T, GARGASZ K, LASKOWSKI R 2011 Does mixed diffuse pollution decrease ground beetle diversity? Balt J Coleopterol 11(1): 1–15

50. SHIBUYA S, KIKVIDZE Z, TOKI W, KANAZAWA Y, SUIZU T, YAJIMA T, FUJIMORI T, MANSOURNIA M R, SULE Z, KUBOTA K, FUKUDA K 2014 Ground beetle community in suburban Satoyama – A case study on wing type and body size under small scale management. Journal of Asia-Pacific Entomology 17: 775–780